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QUANTITATIVE INFLUENCE OF THE  
PERIPHERAL VISION DEVICE  
ON INSTRUMENT FLYING IN A SIMULATOR

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ABSTRACT

Most pilots who have flown the Peripheral Vision Device feel that it reduces the workload in instrument flying, and the device appears, on theoretical grounds, to have antidisorientation effects. The present experiment was undertaken to determine quantitatively whether the device has an influence on instrument flying (in a simulator) during inflight procedures and circumstances known to predispose to disorientation. The device did have a significant effect on instrument flying in some of the circumstances of the tests: it significantly reduced the heading error during recovery from an imposed "unusual attitude", and it significantly reduced the rate-of-climb error that followed a combined failure of one engine and one attitude director indicator. Whether or not the device would be effective in preventing disorientation accidents could not be determined in these trials, since the circumstances of the tests did not reliably cause severe disorientation in the pilots.

## INTRODUCTION

In 1979, the latest year for which the National Transportation Safety Board has made available its "Annual Review of Aircraft Accident Data" for general aviation in the United States, spatial disorientation was a cause (in most cases the cause) of 86 fatal accidents (1). These 86 disorientation accidents comprise 13% of the total of 678 fatal accidents in general aviation that year. Similarly, surveys of military aircraft accidents have revealed (2-9) that a large fraction of fatal accidents is caused by disorientation: reported percentages vary from 10% (8) to 34% (3), reflecting different kinds of flying, different accident rates from other causes, different definitions of disorientation, and different criteria for establishing it as a cause (or the cause) of a fatal accident.

Information about disorientation accidents in airliners is relatively difficult to find, but one report (10) published in 1970 describes 14 "dark night takeoff" accidents in airliners that were probably caused by the oculogravic illusion (11). Another report (12) notes that in the 5-year period from 1971 to 1975 there were seventeen "controlled-flight-into-terrain" (CFIT) accidents in airliners. There is reason to think that most (13), although not all (12) CFIT accidents are caused by disorientation, and of course the CFIT kind of accident is only one of many kinds of disorientation accidents. The number of CFIT accidents in airliners in the 5-year period 1976 to 1980 was reduced to two, presumably because of two influences: (i) widespread pilot education about how disorientation can cause a steeper and lower approach than is perceived, when the approach is made over a "black hole" towards upsloping terrain (13); and (ii) the coming into service of the Ground Proximity Warning System in airliners and the Minimum Safe Altitude Warning System in the controller facilities (12). Although it is impossible to know with certainty why the CFIT accident rate decreased so dramatically after 1975, it was not due to chance (12), and in all likelihood the rate decreased because of the pilot education and hardware that were introduced for that purpose. At the time of the 1980 survey, corporate and military aircraft were, for the most part, still not equipped with the Ground Proximity Warning System, and it is instructive to note that the CFIT accident rate after 1975 did not, apparently, fall in the "unequipped corporate fleets and U.S. military transports" (12). In the apparent absence of published reports, it is not clear whether the pilot education and the hardware were introduced into airline flying on a theoretical basis (i.e. because it was obvious that they would alleviate the problem) or whether their effectiveness was first established by formal trials in simulators or in aircraft.

On theoretical grounds, it is reasonable to think that other kinds of disorientation accidents can similarly be prevented, and that the Peripheral Vision Device (PVD) would be effective hardware (14). This device projects onto the pilot's instrument panel a long bar of light that remains always parallel to the real horizon, in spite of roll

movements of the aircraft; the bar of light also moves up and down on the instrument panel as does the real horizon relative to the aircraft (subject to scaling), in response to pitch movements of the aircraft. Most pilots who have flown the device feel subjectively that it reduces the workload in instrument flying (15,16), but this reduction of workload has not been objectively measured, and in order to know definitely whether the device has an influence on instrument flying in circumstances known to predispose to disorientation in flight (17,18), formal tests were undertaken.

### PROCEDURES

A total of 210 simulator flight tests was performed with 35 pilots. Each "flew" 6 tasks (three different tasks, each task flown twice). Each of the three tasks was flown once with the PVD turned on, and once with the PVD turned off; half of the pilots flew the "PVD-on" test first, and half flew the "PVD-off" test first, to cancel order effects. The PVD-on tests were done only after the pilot had experienced one hour or more of simulator flying with the device on. The PVD was the Garrett Manufacturing B model. The pilots were all professional Canadian Forces pilots, and of course instrument rated, and qualified on type. The tasks were flown in the Aurora CP140 Flight Deck Simulator at the Canadian Forces Base Greenwood, Nova Scotia. This is a modern 4-engined (turboprop) flight simulator with motion base (six degrees of freedom) and computerized visuals, but in fact all the tests were performed "in cloud" so that the visuals did not influence pilot performance. All tests were flown with the autopilot off, the motion base on, and a turbulence of 50% (moderate turbulence). For each trial, the simulator provided a hard copy record of the relevant flight parameters controlled by the pilot, and the pilot performances with and without the PVD were compared.

Task 1: Unusual Attitude. The pilot was instructed to maintain straight and level flight at altitude 3000 feet, heading 360 degrees, and airspeed 220 knots. The perturbation imposed was the sudden assumption of an unusual attitude, the instantaneous change of the aircraft situation to: pitch -30 degrees, bank -80 degrees, and airspeed 330 knots. In response to this insult, the pilot was expected, in accordance with his instructions, to return to level flight at 3000 feet, 360 degrees, and 220 knots. His total error in altitude was considered to be the integral of the aircraft altitude (relative to the assigned altitude) with respect to time for the 120 seconds following the imposition of the unusual attitude. Errors above 3000 feet were added to errors below 3000; both were considered positive errors, and they did not cancel each other. This means, of course, that an altitude error of 1000 feet low for one second is considered equivalent to (and would be added to) an altitude error of 500 feet high for two seconds, and the overall altitude error is the total number of "feet-seconds" accumulated in the 120 seconds. Similarly, the heading error was measured in "degree-seconds" and the airspeed error was measured in "knot-seconds".

The measurements were taken from the hard copy curves provided by the simulator, by measuring the appropriate areas with a planimeter.

Task 2: Engine and ADI Failure. The pilot was instructed to take off from runway 26 and to maintain a climb of 1000 feet per minute on a heading of 260°, to 5000 feet. Shortly after takeoff the perturbation was imposed, and the measurements were always completed before the 5000 ft altitude was reached, so that the task was flown entirely during a period of intended climb. The perturbation imposed was the failure of the number 4 engine, which in this aircraft causes the prompt failure of electrical power to the captain's (left instrument panel's) attitude director indicator, (ADI). Also on the left instrument panel is the standby artificial horizon, so that loss of the ADI did not leave the pilot without an artificial horizon.

The pilot was expected, in accordance with his instructions, to maintain his climb at the rate of 1000 feet per minute and to maintain his heading at 260 degrees. His total error in climb rate was considered to be the integral of the rate of climb (relative to the assigned rate) with respect to time for the 120 seconds following failure of the engine. Errors in climb rate above 1000 were added to errors below 1000; both were considered positive errors and they did not cancel each other. This means, of course, that a climb rate error of 600 feet per minute too high (at 1600 feet per minute, since the assigned climb rate was 1000 feet per minute) for one second is considered equivalent to (and would be added to) a climb rate error of 300 feet per minute too low (at 700 feet per minute) for two seconds. Because the rate of climb information was taken from a paper copy of the "altitude vs time" trace, no measuring of areas was done for this error, and in fact the overall climb rate error was the total number of inappropriate feet (feet per unit time multiplied by time) accumulated during the 120 seconds. The heading error was measured in "degree-seconds" accumulated over the 120 seconds, as in Task 1.

Task 3: The Leans. This perturbation was imposed on the pilot during a part of his exercise that required straight and level cruise at an assigned altitude, heading, and airspeed. The perturbation was a sudden sensation that the aircraft had rolled to the right and was leaning to the right. The aircraft instruments continued to show straight and level flight. This was imposed by using the motion base of the simulator to tilt the cockpit through 20 degrees, at 12 degrees per second and to leave it tilted there. The tilting of the cockpit was done by switching a pre-programmed error into the zero roll position of the motion base, so that the cabin was tilted but the motion base continued to function normally about the new (erroneous) zero roll position. Since the entry into the tilt was rather violent, and since the tilt itself was very apparent, the sensation of leans was quite striking. After 30 seconds of leaning 20° right, the motion base zero setting program again was used to change the tilt from 20 degrees right to 20 degrees left (also at the rate of 12 degrees per second), and after

30 seconds of the left tilt it was changed back to right tilt where it was maintained for a further 30 seconds before returning to level (normal). None of the cockpit tilts were reflected on the ADI or on any other instrument, so that if the pilot did not respond to the tilt it would have no influence whatever on the indicated or recorded flight parameters.

The pilot was expected, according to his instructions, to maintain his assigned altitude and heading during the tilting of the cockpit. His altitude error was measured in feet-seconds over the 120 seconds of recording and his heading error was measured in degree-seconds, by measuring the appropriate areas on the paper traces, as in the other tasks. In this task, the aileron angle and pedal forces were also recorded, instead of airspeed.

### RESULTS

Task 1: Unusual Attitude: The PVD had a measurable influence on the heading error during recovery from the unusual attitude. This influence is illustrated in Figure 1. With the PVD off, the average heading error for all the pilots was 2.57 thousand degree seconds, and with the PVD on this error was only 1.84 thousand, a statistically significant difference (analysis of variance,  $P < .005$ ). In this task there were no other significant differences between the errors with PVD on and PVD off (see Table I).

In addition to the overall errors recorded in Table I, the extreme deviations in altitude, heading, and airspeed were also measured and there were no significant differences between the extreme values (averaged across all of the pilots) with PVD off vs the average extreme values with PVD on. The time to recovery to the pre-insult values was also measured for each of the parameters (altitude, heading, and airspeed) and again there were no significant differences between the times with PVD off and times with PVD on.

Throughout the entire study, because some parameters on occasion failed to print out and the data were therefore lost, the number of available measurements of a given parameter was often 2 or 3 less than 35, although never less than 30.

Task 2: Engine and ADI failure: The PVD had a measurable influence on the rate-of-climb error that followed the engine failure and subsequent ADI failure. This influence is illustrated in Figure 2. With the PVD off, the average rate-of-climb error for all the pilots amounted to 1,406 feet, and with the PVD on this error was only 1,049 feet, a statistically significant difference (analysis of variance,  $P < .001$ ). In this task there were no other significant differences between the errors with PVD on and PVD off (see Table II). As in Task 1, the extreme deviations and the times to recovery were also measured, and these values with PVD on were not significantly different from the values with PVD off.

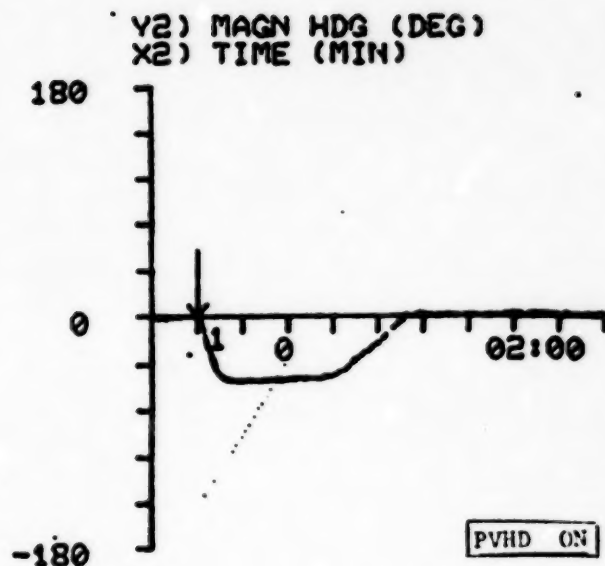
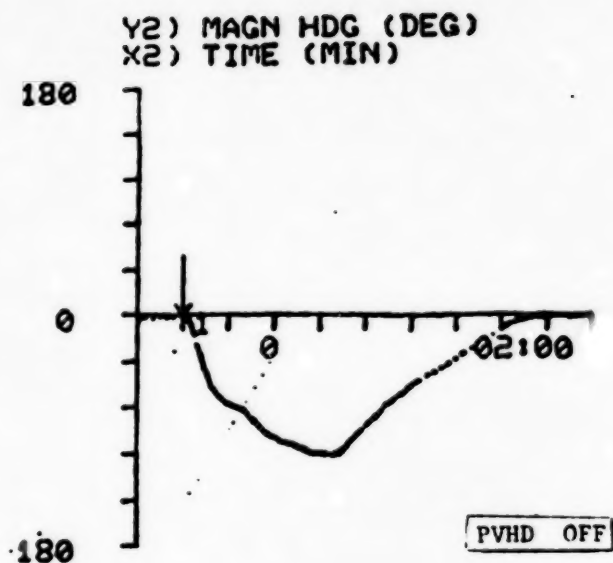


Figure 1 Heading error caused by unusual attitude

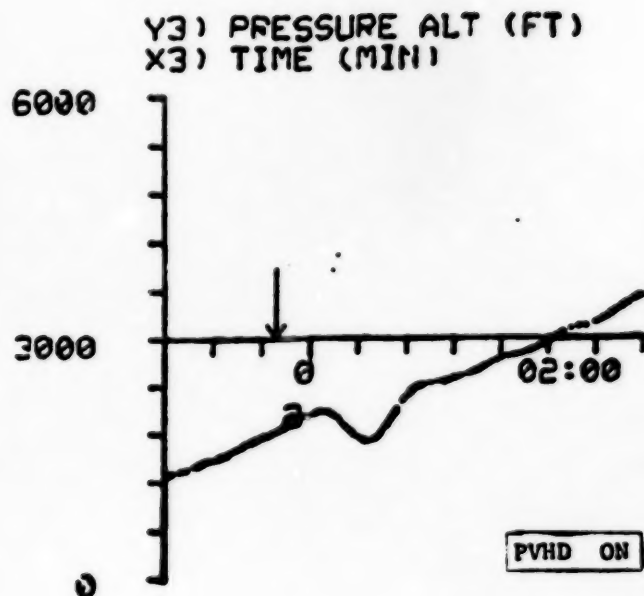
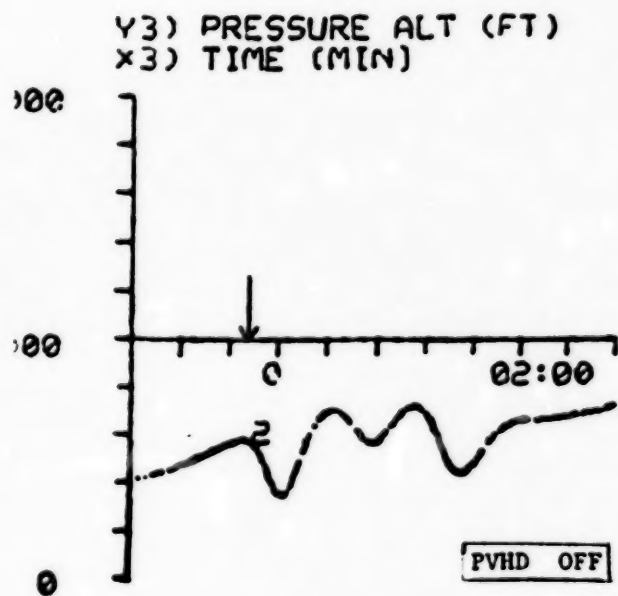


Figure 2 Altitude error caused by engine and ADI failure

↓ indicates where perturbation was imposed

TABLE I

ERRORS CAUSED BY UNUSUAL ATTITUDE (33 pilots)

| PARAMETER | MEAN ERRORS<br>PVD off | MEAN ERRORS<br>PVD on | UNITS      | SIGNIFICANCE<br>PVD off VS on |
|-----------|------------------------|-----------------------|------------|-------------------------------|
| Altitude  | $4.51 \times 10^4$     | $4.29 \times 10^4$    | feet sec   | not significant               |
| Heading   | $2.57 \times 10^3$     | $1.84 \times 10^3$    | degree sec | significant( $p < .005$ )     |
| Airspeed  | $3.34 \times 10^3$     | $3.35 \times 10^3$    | knot sec   | not significant               |

TABLE II

ERRORS CAUSED BY ENGINE AND ADI FAILURE (35 pilots)

| PARAMETER     | MEAN ERRORS<br>PVD off | MEAN ERRORS<br>PVD on | UNITS      | SIGNIFICANCE<br>PVD off VS on |
|---------------|------------------------|-----------------------|------------|-------------------------------|
| Rate of Climb | $1.41 \times 10^3$     | $1.05 \times 10^3$    | feet       | significant( $p < .001$ )     |
| Heading       | $1.57 \times 10^3$     | $1.30 \times 10^3$    | degree sec | not significant               |
| Airspeed      | $1.03 \times 10^3$     | $1.15 \times 10^3$    | knot sec   | not significant               |

TABLE III

ERRORS CAUSED BY THE LEANS (30 pilots)

| PARAMETER | MEAN ERRORS<br>PVD off | MEAN ERRORS<br>PVD on | UNITS      | SIGNIFICANCE<br>PVD off VS on |
|-----------|------------------------|-----------------------|------------|-------------------------------|
| Altitude  | $5.26 \times 10^3$     | $5.45 \times 10^3$    | feet sec   | not significant               |
| Heading   | 81.0                   | 75.6                  | degree sec | not significant               |

Airspeed was not measured for the leans task.

Task 3: The Leans: Although the twenty-degree leans were quite striking, they had only a trifling influence on the maintenance of altitude, heading, and control forces, regardless of whether the PVD was on or off. There were no significant differences between the errors with PVD on and PVD off (see Table III). Similarly, the extreme deviations and recovery times showed no significant differences between values with PVD on and values with PVD off.

#### DISCUSSION

It is clear that the PVD does influence instrument flying, as indicated by the reduced heading error in the "unusual attitude" task and the reduced rate-of-climb error in the "engine and ADI failure" task. These findings in these two tasks are consistent with pilot reports that the device makes instrument flying much easier (having such a large indication of the horizon is thought to be comparable to having the real horizon, i.e. it is comparable to VFR flying). Under the demanding conditions of these two tasks, the job of instrument flying was presumably easier with the PVD on, and the task could therefore be done better.

It is difficult to understand why the PVD influenced the particular two flight parameters that it did and why it had no significant effect on the others. In the leans task, the perturbation was trifling in its influence on instrument flying, regardless of whether the PVD was on; it is not surprising, therefore, that the PVD had no significant effect on the performance of this task, since the PVD would not be expected to increase the precision of instrument flying under essentially normal conditions in pilots who are able and willing to work hard at doing it accurately. In planning the experiment it was thought that the imposition of the leans would be quite stressful, but in retrospect: it is common for well-trained pilots to report that moderate leans are just annoying and do not seriously threaten the control of the aircraft (19). The more spectacular and compelling variety of leans can, of course, result in serious control problems or fatal accidents (20,21), but experienced pilots apparently have no trouble at all with 20 degrees of leans in a simulator.

Considering the three parameters studied in the "unusual attitude" and "engine and ADI failure" tasks (altitude/rate of climb, heading, and airspeed), airspeed is less directly influenced by aircraft attitude and was in fact uninfluenced by the PVD. The altitude (or rate of climb) and heading are more directly influenced by aircraft attitude, and it is perhaps for this reason that they were influenced significantly by the PVD. It is not clear why heading was significantly influenced in the "unusual attitude" task but not in the "engine and ADI failure" task, whereas altitude/rate of climb was significantly influenced in the "engine and ADI failure" task but not significantly influenced in the "unusual attitude" task.

During the series of 210 tests there were 8 occasions when the aircraft altitude was reduced to terrain altitude. Five of the eight "crashes" occurred with the PVD off, and three occurred with it on (not a significant difference). All 8 crashes occurred on a pilot's first exposure to a given task; no crash occurred during a pilot's second exposure to a given task. Four crashes occurred following the engine and ADI failure (all with PVD off), and four occurred following the unusual attitude (one with PVD off, and three with PVD on). The subjective reduction of workload in instrument flying that the PVD provides (15,16) might have had a stronger (and significant) effect in preventing crashes in these tests if the test altitudes had been chosen differently; but the occurrence of crashes only on "first" trials shows that recent experience with these particular tasks is sufficient to prevent a crash.

The ability of the PVD to prevent control loss because of spatial disorientation was, unfortunately, not tested. The leans task provoked no loss of control even with the PVD off. Although, on theoretical grounds (14,22), it seems clear that the PVD has strong antidisorientation effects and that it would prevent accidents if it were used, it would probably require very large numbers of trials in aircraft, at great cost, to establish unequivocally its effectiveness in this regard (or to establish unequivocally the effectiveness of any effective antidisorientation instrument). The reason for this is that inflight demonstrations of the compromising of aircraft control with disorientation are usually unsuccessful; they are successful only occasionally (23). Although almost all pilots have experienced disorientation (24,25), although the predisposing circumstances are well known (17,18), and although techniques for dealing with it are known to pilots (26-28), knowledge of most kinds of disorientation is incomplete and insufficient to allow the experimental production of control loss from disorientation in flight except occasionally (23).

This inability to cause control loss with disorientation experimentally is comparable to the inability of disorientation to cause frequent serious control loss in operational flying. In operational flying, the number of disorientation experiences that seriously compromise aircraft control is a very small fraction of the total number of disorientation experiences. In one study, for example, "six hundred and eighty-five pilots indicated having had perhaps many thousands of "vertigo" experiences, but only 20 incidents were recorded which were considered to be "near-accidents" (29).

Historically, there have been only a few major advances in dealing with spatial disorientation in flight. Originally, flight in darkness or in cloud was exceedingly dangerous because without visual contact with the ground, and without orientation instruments, attitude control was impossible. The impossibility was not immediately understood, and as late as 1917 it was thought that in darkness or in cloud

the pilot must rely "preeminently on his ear balance sense" (30), and pilots were taught the doctrine of "flying instinct" (31) for "blind flight". In 1919 Ocker flew in cloud using one of Sperry's first turn indicators, making the first major advance. He showed that instrumentation could make "blind flight" possible (32), but he was unable to interest others (or the Air Corps) in the instruments until some 7 years later (32). This major advance in dealing with disorientation (use of flight instruments) was essentially unnoticed for seven years after it was made.

In 1926 Ocker was given a Barany chair rotation test as part of his annual aircrew medical examination. He requested and received a second rotation test with his flight instruments, and made the second major advance: he found that his sensations of orientation could be compelling and incorrect, that the pilot not only needed flight instruments, he needed to ignore his false sensations and believe his instruments (33). This understanding was sufficient to sweep away, finally, the "flying instinct" doctrine and the idea that flight instruments often "went haywire in fog" (31), although the process took a few years. As late as 1930, Ocker wrote (32) "Until very recently, all flying students were taught to disregard flight instruments and trust entirely to their "flying instinct" even in fog." Unfortunately, it was thought that with the available instrumentation and the subsequent pilot education, that the disorientation problem had been solved.

During World War II and the period immediately following, aircraft accidents were only rarely attributed to "pilot's vertigo". This appears to be so because of a general belief that the problem of "blind flight" had been solved by appropriate instrumentation and appropriate education and training of pilots." (29,33). It was not until the 1950's that it came to be generally known that disorientation accidents were still happening and that they were happening frequently even in fully trained pilots (29,34,35). Perhaps the third major advance was the installation of the Ground Proximity Warning Systems (12), but it is well known that disorientation accidents are still occurring with (literally) hundreds of fatal crashes annually.

#### CONCLUSIONS

1. It was found that the PVD does cause a measurable improvement in certain aspects of instrument flying under circumstances of flight that are known to predispose to spatial disorientation.

2. Because the procedures used did not disorient the pilots sufficiently to degrade aircraft control even when the PVD was turned off, it was not possible to demonstrate whether the PVD prevents disorientation.

### RECOMMENDATIONS

One type of disorientation that is experienced frequently in CF flying is the marginal orientation of pilots during landing of the Sea King helicopter on the DDH deck at night. It is reasonable to think that an assessment of these landings with the PVD would prove whether or not it is effective in improving orientation under circumstances in which orientation is known to be compromised. Such assessment should include landings with and without the PVD, and the study should include questionnaires to be completed by the pilots, measurements of the pilot's eye movements, and an objective measure of the landing quality (possibly the G forces of landing and the total time required).

To provide a valid assessment, the data should be collected over a period of at least 12 months with the same group of pilots using the device continuously. This lengthy period of assessment is necessary since, from previous studies (16,36) and Canadian Forces experience in the CP 121 Tracker aircraft, operational pilots need to fly the device for a considerable number of hours before they can benefit from it.

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**POOR**

**QUALITY**

**ORIGINAL**

